Influence of Cover Crops on Insect Pests and Predators in Conservation Tillage Cotton

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ABSTRACT In fall 2000, an on-farm sustainable agricultural research project was established for cotton, *Gossypium hirsutum* L., in Tift County, Georgia. The objective of our 2-yr research project was to determine the impact of several cover crops on pest and predator insects in cotton. The five cover crop treatments included 1) cereal rye, *Secale cereale* L., a standard grass cover crop; 2) crimson clover, *Trifolium incarnatum* L., a standard legume cover crop; 3) a legume mixture of balansa clover, *Trifolium michelianum* Savi; crimson clover; and hairy vetch, *Vicia villosa* Roth; 4) a legume mixture + rye combination; and 5) no cover crop in conventionally tilled fields. Three main groups or species of pests were collected in cover crops and cotton: 1) the heliothines *Heliothis virescens* (F.) and *Helicoverpa zea* (Boddie); 2) the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois); and 3) stink bugs. The main stink bugs collected were the southern green stink bug, *Nezara viridula* (L.); the brown stink bug, *Euschistus servus* (Say); and the green stink bug, *Acrosternum hilare* (Say). Cotton aphids, *Aphis gossypii* Glover, were collected only on cotton. For both years of the study, the heliothines were the only pests that exceeded their economic threshold in cotton, and the number of times this threshold was exceeded in cotton was higher in control cotton than in crimson clover and rye cotton. Heliothine predators and aphidophagous lady beetles occurred in cover crops and cotton during both years of the experiment. *Geocoris punctipes* (Say), *Orius insidiosus* (Say), and red imported fire ant, *Solenopsis invicta* Buren were relatively the most abundant heliothine predators observed. Lady beetles included the convergent lady beetle, *Hippodamia convergens* Guérin-Méneville; the sevenspotted lady beetle, *Coccinella septempunctata* L.; spotted lady beetle, *Coleomegilla maculata* (DeGeer); and the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas). Density of *G. punctipes* was higher in cotton fields previously planted in crimson clover compared with control cotton fields for all combined sampling dates in 2001. Intercropping cotton in live strips of cover crop was probably responsible for the relay of *G. punctipes* onto cotton in these crimson clover fields. Density of *O. insidiosus* was not significantly different between cover crop and control cotton fields. Lady beetles seemed to relay from cover crops into cotton. Conservation of the habitat of fire ants during planting probably was responsible for the higher density of red imported fire ants observed in all conservation tillage cotton fields relative to control cotton fields. Reduction in the number of times in which economic thresholds for heliothines were exceeded in crimson clover and rye compared with control fields indicated that the buildup of predaceous fire ants and *G. punctipes* in these cover crops subsequently resulted in reduction in the level of heliothines in conservation tillage cotton with these cover crops compared with conventional tillage cotton without cover crops.

KEY WORDS cover crops, predators, cotton

COTTON, *Gossypium hirsutum* L., is the fifth largest crop in the United States in terms of acreage in production. Trends in current prices indicate that producers in the United States will have a difficult time remaining competitive in a global market (Shurley et al. 2000). Therefore, efficient management strategies are needed to help reduce production costs. Conservation tillage and cover crops can help reduce production costs through improved soil water relationships and long-term soil productivity, increased habitat for beneficial insects and greater agroecosystem stability (Altieri 1994, Reeves 1994). As a result of

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frequent and intense disturbance, many agricultural systems are recognized as particularly difficult environments for natural enemies (Landis and Marino 1999). Conservation tillage along with cover crops reduces this frequent disturbance and helps promote year-round natural enemy and pest species interactions by providing alternate prey or hosts, reproductive sites, and protection from adverse conditions. Cover crops in reduced tillage systems offer a simple approach to pest management, but more information on the impact of cover crops on targeted pests and predators are needed to facilitate design of appropriate landscapes.

Cereal rye, *Secale cereale* L., is a standard grass cover crop in the United States. It flowers in April through May and matures in May or June (Hitchcock 1971) and can harbor many species of aphidophagous lady beetles (Bugg et al. 1990a). Crimson clover, *Trifolium incarnatum* L., is a standard legume cover crop that flowers in April through May and matures in May or June in Georgia (Finch and Sharp 1976). Crimson clover has showy, deep red blossoms that produce nectar and are visited frequently by bees (Knight 1985). The blooms also harbor beneficial insects such as *Geocoris punctipes* (Say) (Bugg et al. 1991). Hairy vetch, *Vicia villosa* Roth, is a widely adapted legume cover crop. In Georgia, it grows as a winter annual and flowers April through early to mid-June (Goar 1934). Beneficial insects such as *Orius insidiosus* (Say) and *G. punctipes* can be abundant in hairy vetch (Bugg et al. 1990a). Balansa clover, *Trifolium michelianum* Savi, a cool-season annual legume first released in Australia in 1985 (Craig and Beale 1985), flowers earlier than crimson clover and hairy vetch (Craig et al. 1998) and is very attractive to bees (Dear 2000).

A significant amount of research has been conducted on using rye, crimson clover, and hairy vetch as cover crops in conservation tillage systems in the south (Reeves 1994). Further research has focused on the use of these cover crops with conservation tillage in cropping systems in the south to enhance beneficial insects (Bugg et al. 1991, McCutcheon et al. 1995, Ruberson et al. 1995, Ruberson et al. 1997, McCutcheon 2000). Most studies have focused on comparisons among single species of legumes and nonlegumes (Reeves 1994). No studies have addressed the impact of using mixtures of legume species as winter cover crops in cotton on natural enemies even though they can provide a more diverse biological habitat through an extension of availability of nectar and other food sources (Altieri 1995). The objective of our 2-yr on-farm research project in Tift County, Georgia, was to determine the impact of cereal rye, crimson clover, a legume species mixture (balansa clover, crimson clover, and hairy vetch), and a combination of this legume mixture and rye on pest and predator insects in cotton.

Materials and Methods

Treatments. The five cover crop treatments included 1) cereal rye ('Wrens Abruzzi'), a standard grass cover crop; 2) crimson clover ('Dixie'), a standard legume cover crop; 3) a legume mixture of balansa clover ('Paradana'), crimson clover, and hairy vetch; 4) a legume mixture + rye combination; and 5) no cover crop in conventionally tilled fields. The mixture of an early (balansa clover), mid- (crimson clover), and late (hairy vetch) flowering legume was chosen to extend the availability of a habitat of flowering plants in the field that could be attained from planting any legume species alone. For the legume mixture–rye treatment, the rye was planted in the center of the row where the cotton would be planted in the summer, whereas the legume mixture was planted on each side of the rye. The combination of the legume mixture and rye was chosen in an effort to combine the benefits of legume nectar production and nitrogen fixation with enhanced biomass production of rye.

Cover crops were planted using a John Deere (Deere and Co., Moline, IL) grain drill with 21 drills with 18-cm spacing. Rye and crimson clover treatments were planted at a rate of 56 and 16.8 kg of seeds per hectare, respectively. For the legume mixture, rates of 1.01, 3.47, and 2.13 kg of seeds per hectare were used for balansa clover, crimson clover, and hairy vetch, respectively. In fall 2000, cover crops were planted from 5 December 2000 to 20 December 2000. All cover crops, except for one crimson clover field that had excellent reseeding, were replanted in fall 2001 from 28 November 2001 to 21 December 2001. We were unable to plant all treatments on the same day because we had only one grain drill and fields were dispersed throughout Tift County.

Cover crop growth and ground coverage were determined by visual observations of overall growth and percentage of ground covered by the cover crops in 50-m^2 sampling plots. This was done for 21 plots per field for each week from the first week after planting to plant senescence.

All of the cover crops, except for rye, were strip-killed in the center of the row with a herbicide ≈3 wk before cotton planting. Rye was broadcast sprayed because it was extremely difficult to maintain row patterns in this tall plant. Paraquat (Gramoxone 2.5 [2.23 liters/ha], Syngenta, Greensboro, NC) + diuron (Direx 4 [2.23 liters/ha], DuPont, Wilmington, DE) was used to strip-kill the cover crops. In spring 2001, a six-row boom-sprayer (Newton and Crouch, Inc., Albany, GA) was calibrated to deliver 130 liters of herbicide per hectare at a ground speed of 3.1 km/h. Using four 4004E nozzles (Teejet Spraying Systems, Wheaton, IL) and maintaining the spray nozzle at ≈75 cm above the ground, a 46-cm strip of cover crop was killed in the center of the row leaving a 46-cm strip of live cover crop between dead strips to provide insect habitat for relay of insects from the cover crop to cotton. In spring 2002, a hooded sprayer was used to strip-kill crimson clover, the legume mixture, and rye in the legume mixture–rye treatments. The KMC (Kelley Manufacturing Co., Tifton, GA) hooded sprayer was calibrated to deliver 130 liters/ha of herbicide per hectare at a ground speed of 3.1 km/h.

Using three 950 15 EVS nozzles (Teejet Spraying Systems) a strip of cover crop ≈53 cm in width was killed in the center of the row leaving 38-cm strips of live cover crop. In 2002, cover crops were strip-killed from 16 April 2001 to 11 May 2001. The following spring, this process was accomplished from 4 April 2001 to 6 May 2001. We were unable to strip-kill all treatments on the same day because we had a single piece of equipment for applying herbicide to widely separated fields in the county.

Cotton Planting and Yield. Cotton was strip-tilled using cotton producers' KMC strip-till rigs. Cotton was planted at 11.2 kg/ha on all fields by using John Deere planters either during or after strip-tilling the cover crops. Planting dates of cotton ranged from 1 May 2001 to 30 May 2001 the first year of the test and from 26 April 2002 to 11 May 2002 the second year. Cotton varieties included DP 458, DP 5415, DP 5690, and Delta Pearl (Delta and Pine Land, Co., Scott, MS). Cotton planting dates were variable due to differences in strip-killing dates and variability in responsibilities of cotton producers that planted the cotton. Cotton producers were asked to plant a single cotton variety but sometimes decided to do otherwise. In 2001, one legume mixture–rye field was not planted in cotton because the cotton producer harrowed the cover crop into the soil, and one rye field was not planted because the cotton producer decided not to plant cotton in that field for that particular season.

Cotton was harvested by cotton producers using John Deere cotton pickers. One or two four-row swaths of cotton 120–150 m in length were picked in each field. Lengths of swaths harvested were variable due to decisions of cotton producers. In 2002, only one swath of cotton was harvested in one legume mixture–rye field, two legume mixture fields, one rye field, and all control fields because cotton producers were in a hurry to harvest the cotton. Using a weigh wagon, cotton was weighed immediately after machine harvest in the field to determine seed-cotton yields. We were unable to obtain cotton lint yields because the cotton producers wanted the harvested cotton. In the fall of 2001, cotton was harvested from 16 October 2001 to 3 December 2001 and the following year from 10 October 2002 through 21 November 2002. Seed-cotton yield data were analyzed by PROC MIXED followed by least significant difference (LSD) separation of means (SAS Institute 1999) where appropriate. Fixed effects were cover crop treatments and random effects were cotton producers' fields and residual error. In 2001, one crimson clover field was not included in this analysis because ≈25% of the ground cover in this field was volunteer wheat and rye. In 2002, one legume mixture-rye field was not included in the yield analyses because the cotton producer harvested this field together with several other fields, and so a yield could not be obtained for this field. All of the fields were evaluated for seedling diseases, soil-dwelling arthropods, plant parasitism by nematodes, nutrient cycling and water availability by cooperators in the project, but these findings will be reported in subsequent articles.

Experimental Design and Insect Samples. Twenty fields were found in various locations in Tift County. These fields were owned and operated by three well established cotton producers in the county. The Tift County extension agent determined that each of these fields constituted a population of fields suitable for growing cotton before this experiment was conducted. Large 4-ha fields were used for each cover crop treatment to limit dispersal of predators from the fields. Each cover crop treatment was assigned randomly to four fields similar to a completely randomized design. The same fields were used for the same cover crop treatments for the 2-yr project except one crimson clover and one rye field were eliminated from the study because the cotton producer decided he did not want to plant any crop in that field that year. Statistical testing demanded that the experimental units were independent from each other and that the treatments were assigned at random to the experimental units (Box et al. 1978). The completely randomized design served as the main plot portion of the following split plot description. Each field was completely subdivided into 50-m^2 sampling plots. Then each field was partitioned into three sampling locations: 1) side, an outer edge of the field with a single layer of the sampling plots; 2) center, one of four of the sampling plots in the center of the field; and 3) section, one of three to four sections or divisions of the field with the remaining sampling plots. Insect pests and predators on plants were sampled each sampling week in each cover treatment for cover crops in the spring and cotton in the summer by using sweep nets 38 cm in diameter. A 6.1-m sweep sample was obtained from each of the sampling plots swept for insects. In each field, 20–21 sampling plots, five from each section for fields with three sections or four from each section for fields with four sections, one from each side, and one from the center, were sampled. The experimental design describes a split plot in space (sampling location) and time (sampling weeks) with subsamples present in the sections (Steel and Torrie 1960). Different sets of random numbers were created for sweeping sampling plots for each sampling location for each sampling week for both crops (cover crop and cotton). This was to ensure that the requirement for random sampling was met and also that none of the sampling plots in the sections (location three above) of the field were sampled more than once throughout the season. Specific sampling plots were located in the field using global positioning system (GPS) technology (Trimble, Sunnyvale, CA). Collecting samples each week was a replication of the experimental design, and because the same sampling scheme was used for every field, each field was a replication of the sampling design (Steel and Torrie 1960).

Cover crops were sampled using sweep nets on a weekly basis from the seedling stage until cotton was planted. No samples were obtained for 2 wk after cotton planting to be sure that cotton seedlings would not be damaged. Then preflowering and flowering cotton was swept on a weekly basis. In 2001, cover crops for the blend + rye and rye treatments were sampled for 10 wk beginning 28 March 2001 and ending 30 May 2001. The crimson clover and legume mixture treatments were sampled weekly for 11 wk starting also at the end of March, but ending on 6 June 2001. Cotton was sampled for 5 wk starting 27 June 2001 and ending 31 July 2001. In 2002, all cover crops were swept weekly for 9 wk starting on 25 March 2002 and ending 20 May 2001, and cotton was sampled for 4 wk beginning on 10 June 2002 and ending on 5 July 2002.

In cotton, exhaustive whole plant sampling was done to monitor heliothine species. Sampling occurred weekly before the heliothines *Heliothis virescens* (F.) and *Helicoverpa zea* (Boddie) occurred on cotton and biweekly thereafter. The sampling scheme was similar to that for sweep sampling, except that a single plant was sampled in each of the 50-m^2 sampling areas. Before heliothine females began laying eggs, 20–21 plants were examined using the sweep sampling scheme. When heliothine females were laying eggs in the field, 44–45 plants, 13 from each section for fields with three sections or 10 from each section for fields with four sections, one from each side, and one from the center, were examined per field. Heliothine eggs were present in cotton fields from 9 July 2001 to 27 August 2001 the first year of the test and from 17 June 2002 to 19 August 2002 the second year of the test. Voucher specimens of all insects are held in the USDA–ARS, Crop Protection and Management Research Laboratory in Tifton.

Preliminary analyses of insect pest and predator data showed that variances were not homogenous between individual fields and crop type (cover crop or cotton) present in the field at the time samples were taken. Square-root transformation of the data was performed to stabilize the variances. Square-root transformation was used because none of the individual counts exceeded 100, and log transformation of the data presented similar results compared with the square-root transformation. Results of the square-root transformation did not resolve the problem of heterogeneity of variances. Therefore, insect pest and predator density data from sweep and whole plant samples were analyzed by PROC MIXED (SAS Institute 1999) to obtain least squares means and their associated standard errors (containing information about the size of the sample taken at each location at each sampling week). Fixed effects were sample location, sample week, and sample location × sample week. Using the rules associated with unequal sample size and unequal variance *t*-tests, the three sampling locations were pooled to obtain field by crop type by sampling week least squares means and standard errors. By using the same rules for unequal sample size unequal variance *t*-tests, data for each field with the same cover crop were pooled to obtain least squares means for cover crop by sampling week, and then sampling weeks were pooled to obtain least squares means and standard errors for cover crop by crop type. If no insects were found in a field during a sampling week, the field was not included in the pooling of the data because the variance could not be estimated. Comparisons between crop types (cover crop or cotton) for individual sampling weeks and sampling weeks combined were performed for each cover crop treatment except control cotton using one-tailed *t*-tests. Comparisons between cover crop treatments were then performed for each crop type by using one-tailed *t*-tests (Mullinix and Baird 1997). Comparisons between least squares means were performed using square-root transformed data because this data transformation has a greater effect on the standard error than on the least squares mean, which results in an improved *t*-test capability compared with untransformed data.

Economic Thresholds. In this study, the economic threshold for heliothines was 5% infestation of first instars on cotton plants. For stink bugs (nymphs and adults), the economic threshold was 20% of the medium-sized bolls (≈14 d old) with internal feeding damage. Economic threshold for tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (nymphs and adults), was considered to be reached when plants were retaining <85% of the pinhead squares. Economic threshold for cotton aphid, *Aphis gossypii* Glover (all forms), was abundant aphids with slightly curled seedling leaves. The number of dates where the level of *H. virescens* and/or *H. zea* exceeded the economic threshold was analyzed by PROC GLM followed by LSD separation of means (SAS Institute 1999) where appropriate.

Results

For both years of this on-farm conservation tillage cover crop research in cotton, growth of each cover crop was excellent and ground coverage was good, 85–100%, except for one field. In 2002, a single crimson clover field had volunteer wheat and rye growing patchily in ≈25% of the field. Flowering began in late March for balansa clover and rye, early April for crimson clover, and late April for hairy vetch. Flowering ceased in late April for balansa clover and rye, mid-to-late May for crimson clover, and early June for hairy vetch.

Four main groups or species of pests were collected in sweep samples: 1) aphids, 2) tarnished plant bugs, 3) stink bugs, and 4) heliothines *H. virescens* and *H. zea.* The aphid species collected depended on the crop. The legumes harbored the pea aphid, *Acyrthosiphon pisum* (Harris), whereas rye harbored the bird cherry-oat aphid, *Rhopalosiphum padi* (L.). The cotton aphid, which is an economic pest throughout the Cotton Belt (King and Phillips 1989), has a wide host plant range. In a review on the biology of this pest, Elbert and Cartwright (1997) reported >90 plant families, including the legume family, in which a least one species was listed as a host. In our study, however, the cotton aphid infested only cotton plants, and so only aphid data from cotton were analyzed.

L. lineolaris is a pest in cotton in the southeastern Unites States (Hanny et al. 1977). More than 300 plant species, including crimson clover and hairy vetch, have been reported as host plants of this pest insect (Young 1986).

Table 1. Least squares means for pest insects in sweep samples for all cover crop treatments in 2001

Crop type	Treatment	n[a]	Aphids[b]	n	Stink bugs[c]	n	Tarnished plant bugs[d]	n	Heliothine larvae
Cover crop	Legume mixture[e]			1067	0.55 ± 0.01a1	1067	1.68 ± 0.05a1	1067	0.55 ± 0.01a
	Crimson clover			1004	0.56 ± 0.01a1	1004	1.39 ± 0.04b1	1004	0.56 ± 0.01a
	Legume[f] + rye			738	0.52 ± 0.01b1	738	0.70 ± 0.02c1	738	0.51 ± 0.01b
	Rye			724	0.56 ± 0.01a1	724	0.55 ± 0.01d1	724	0.50 ± 0.01b
Cotton	Legume mixture	439	0.77 ± 0.06c	105	0.51 ± 0.02a2	230	0.52 ± 0.01a2		
	Crimson clover	384	1.35 ± 0.11ab	181	0.51 ± 0.01a2	384	0.54 ± 0.02a2		
	Legume + rye	315	0.74 ± 0.08c	315	0.51 ± 0.01a	315	0.53 ± 0.01a2		
	Rye	315	1.65 ± 0.13a	105	0.52 ± 0.02a2	315	0.52 ± 0.01a2		
	Control	420	1.19 ± 0.04b	420	0.50a	420	0.52 ± 0.01a		

Least squares means within a column followed by the same number are not significantly different between crop types for a single cover crop treatment, and least squares means within a column followed by the same letter are not significantly different between cover crop treatments for a single crop type (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for rye and legume mixture + rye treatments are *n*-30 for cover crop type. Degrees of freedom for crimson clover and the legume mixture are *n*-33 for cover crop type. Degrees of freedom for all treatments in the cotton crop type are *n*-15.

[b] All forms.

[c] Nymphs and adults.

[d] Nymphs and adults.

[e] Legume mixture is balansa clover, crimson clover, and hairy vetch.

[f] Legume mixture.

Even though stink bugs have been reported as pests of cotton since the beginning of the 20th century (Morrill 1910), stink bugs recently have emerged as pests of increasing importance (Greene and Turnipseed 1996). The main stink bugs collected in this study were southern green stink bug, *Nezara viridula* (L.); brown stink bug, *Euschistus servus* (Say); and green stink bug, *Acrosternum hilare* (Say). The host plant range of the southern green stink bug encompasses >30 families of dicots and some monocots (Todd 1989). These stink bugs seem to have a strong preference for certain legumes (Todd 1989). They have been reported to breed on red clover, *Trifolium pratense* L. (Newsom et al. 1980), but they have not been specifically reported to feed on crimson clover and hairy vetch. The brown stink is polyphagous, feeding on soybean, *Glycine max* (L.) Merr., and rye and several uncultivated hosts, including *Vicia* spp. and crimson clover in southeastern United States (Jones and Sullivan 1982). Several cultivated plants, especially soybean, and uncultivated plants, particularly black cherry, *Prunus serotina* Ehrhart, and elderberry, *Sambucus canadensis* L., are host plants for the green stink bug (Jones and Sullivan 1982).

H. zea and *H. virescens* are two of the most economically important pests of cotton in the United States (Williams 2003). Both pests have been reported to feed on crimson clover and *Vicia* spp., including hairy vetch (Barber 1937; Stadelbacher 1980, 1981; Mueller and Phillips 1983). We were unable to collect heliothines in cotton sweeps; thus, data on these insects were compared only in cover crops for this sampling technique. Whole plant sampling data were used to compare densities of heliothines between cover crop treatments in cotton.

Cotton aphid densities were significantly higher on rye cotton, not significantly different on crimson cover cotton and significantly lower on cotton for both legume mixture treatments compared with control cotton in the first year of the experiment (Table 1). However, in 2002, cotton aphids were significantly higher in all cover crop treatments except crimson clover compared with control cotton (Table 2). Even though abundance of cotton aphids varied between treatments in cotton during the 2-yr study, cotton aphid densities never exceeded the economic threshold for this pest in cotton.

Stink bug densities were significantly higher in cover crops than in cotton for both years of the study (Tables 1 and 2). Two cover crops, crimson clover and the mixed legume, harbored the highest numbers of stink bugs. In cotton, stink bug abundance was not significantly different among all cover crops treatments, including the controls, and levels of stink bugs never exceeded economic threshold in any field of cotton. Thus, the presence of stink bugs in the cover crops subsequently did not increase stink bug pressure in cotton. Stink bugs have not been reported as pests on cotton when rye and/or crimson clover were used as cover crops in cotton (McCutcheon et al. 1995; Ruberson et al. 1995, 1997; McCutcheon 2000). Stink bugs are very mobile insects and may disperse to more attractive crops such as soybean or corn, *Zea mays* L., when winter cover crops senesce or are killed by herbicides.

For both years of the study, tarnished plant bugs were significantly higher in cover crop treatments with a legume than in rye and higher in the legume–rye mixture than in rye alone, indicating that this pest was more attracted to the legumes than to rye (Tables 1 and 2). Similar to the finding by Bugg et al. (1990b), tarnished plant bugs were significantly higher in the legume mixture with hairy vetch than in the crimson monoculture in 2001. In our study, differences in numbers of tarnished plant bugs among legume cover crop treatments dissipated in cotton, and densities of the pest in cover crop cotton were either similar to or lower than that for control cotton. In addition, no

Table 2. Least squares means for pest insects in sweep samples for all cover crop treatments in 2002

Crop Type	Treatment	n^a	Aphids[b]	n	Stink bugs[c]	n	Tarnished plant bugs[d]	n	Heliothine larvae
Cover crop	Legume mixture[e]			891	0.57 ± 0.01b1	891	1.26 ± 0.02a1	567	0.54 ± 0.01a
	Crimson clover			729	0.62 ± 0.01a1	729	1.22 ± 0.02a1	567	0.52 ± 0.01ab
	Legume[f] + rye			891	0.54 ± 0.01c1	891	0.68 ± 0.01b1	405	0.51 ± 0.01bc
	Rye			567	0.51 ± 0.00d1	729	0.55 ± 0.01c1	729	0.50 c
Cotton	Legume mixture	336	3.02 ± 0.05b	120	0.51 ± 0.01a2	192	0.51 ± 0.01b2		
	Crimson clover	264	1.73 ± 0.04e	120	0.51 ± 0.01a2		0.5b2		
	Legume + rye	336	2.79c	120	0.51 ± 0.01a2	264	0.51 ± 0.01b2		
	Rye	336	3.29 ± 0.06a	120	0.51 ± 0.01a1	264	0.52 ± 0.01ab2		
	Control	336	2.56 ± 0.05d	120	0.52 ± 0.01a	336	0.54 ± 0.01a		

Least squares means within a column followed by the same number are not significantly different between crop types for a single cover crop treatment, and least squares means within a column followed by the same letter are not significantly different between cover crop treatments for a single crop type (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for all treatments are *n*-27 for cover crop type. Degrees of freedom for all treatments in the cotton crop type are *n*- 12.

[b] All forms.

[c] Nymphs and adults.

[d] Nymphs and adults.

[e] Legume mixture is balansa clover, crimson clover, and hairy vetch.

[f] Legume mixture.

insecticide applications were necessary for control of these pests for the 2-yr test. Our conclusion that the presence of tarnished plant bugs in the cover crops did not generate a tarnished plant bug problem in cotton is in agreement with the literature regarding the effect of cover crops on this pest in cotton (Gaylor and Foster 1987, Ruberson et al. 1995). Like stink bugs, these pests are highly mobile and may disperse from cover crop fields when disturbed by agronomic practices.

The number of heliothine larvae was significantly higher in the legume mixture and crimson clover cover crops than in rye, whereas the density of these pests in legume mixture was intermediate between the other two legume cover crops and rye for both years of the test (Tables 1 and 2). In 2001, the number of heliothine eggs and first instars per cotton plant was not significantly different among cover crop treatments (Table 3). However, the number of times in which the heliothines exceeded their economic threshold in cotton was significantly higher in control cotton than in crimson clover and rye cotton in 2001 ($F = 3.04$, df = 4, 13, $P = 0.05$) and 2002 ($F = 3.07$, df = 4, 13, $P = 0.05$). In 2002, the number of heliothine eggs per cotton plant was not significantly different between control cotton and all legume treatments, but it was significantly lower for rye cotton compared with cotton for the other treatments (Table 4). In contrast to the results for the first year of the test, greater numbers of first instars of heliothines were found on control and legume mixture–rye cotton compared with the other three cover crop treatments for the second year of the test. In 2002, the number of times in which the heliothines exceeded their economic threshold in cotton again was significantly higher in control cotton than in crimson clover and rye cotton ($F = 3.07$; df = 4, 13; $P = 0.05$), reflecting the results from the density of heliothines on cotton for these treatments. We conclude that the presence of heliothines in the cover crops did not increase the insect pressure by these pests in cotton in this study. Similar to our findings, Ruberson et al. (1995) reported that four insecticide treatments were required for control of heliothines in a conventionally tilled cotton field

Table 3. Mean number heliothine eggs and first instars per cotton plant and mean number of dates in which heliothines exceeded the economic threshold in cotton for all cover crop treatments in 2001

Treatment	No. heliothines/cotton plant			Times exceeded economic threshold	
	n^a	Eggs	1st Instars	n^b	Mean
Control	484	0.54 ± 0.01a	0.51 ± 0.01a	4	2.0 ± 0.41a
Legume mixture[c] + rye	527	0.56 ± 0.02a	0.51 ± 0.01a	3	1.3 ± 0.33ab
Legume mixture	707	0.54 ± 0.02a	0.51 ± 0.01a	4	1.0 ± 0.41ab
Crimson clover	696	0.57 ± 0.02a	0.50 ± 0.01a	4	0.75 ± 0.25b
Rye	487	0.57 ± 0.02a	0.51 ± 0.01a	3	0.3 ± 0.33b

Heliothine density least squares means within a column followed by the same letter are not significantly different between cover crop treatments (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$). Economic threshold means within a column followed by the same letter are not statistically different between treatments (PROC GLM, LSD, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for control, legume mixture + rye, legume mixture, crimson clover and rye treatments are *n*-68, *n*-69, *n*-89, *n*-83, and *n*-60, respectively.

[b] Refers to the number of fields for each cover crop treatment.

[c] Legume mixture is balansa clover, crimson clover, and hairy vetch.

Table 4. Mean number heliothine eggs and first instars per cotton plant and mean number of dates in which heliothines exceeded the economic threshold in cotton for all cover crop treatments in 2002

Treatment	No. heliothines/cotton plant			Times exceeded economic threshold	
	n^a	Eggs	1st Instars	n^b	Mean
Control	1736	0.58 ± 0.01a	0.52 ± 0.01a	4	3.3 ± 0.63a
Legume mixture[c] + rye	1768	0.61 ± 0.02a	0.51 ± 0.01a	4	2.3 ± 0.48ab
Legume mixture	1691	0.61 ± 0.02a	0.4 ± 0.01c	4	2.0 ± 0.41ab
Crimson clover	1319	0.59 ± 0.02ab	0.49 ± 0.01b	3	1.7 ± 0.33b
Rye	1235	0.53 ± 0.01b	0.49 ± 0.01b	3	1.0 ± 0.33b

Heliothine density least squares means within a column followed by the same letter are not significantly different between cover crop treatments (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$). Economic threshold means within a column followed by the same letter are not statistically different between treatments (PROC GLM, LSD, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for control, legume mixture + rye, legume mixture, crimson clover and rye treatments are *n*-116, *n*-113, *n*-113, *n*-81, and *n*-84, respectively.

[b] Refers to the number of fields for each cover crop treatment.

[c] Legume mixture is balansa clover, crimson clover, and hairy vetch.

without a cover crop, whereas only one treatment was necessary in a reduced tillage cotton field with crimson clover as a cover crop. Gaylor et al. (1984) reported that damage to cotton by the heliothine pests *H. virescens* and *H. zea* in conservation tillage plots was not statistically different from damage in conventional tillage plots. In addition, during peak egg lay, heliothine larvae per 100 cotton plants were numerically three times lower in crimson clover plots than in conventional tillage plots. Increased problems with these two heliothine species, nonetheless, have been reported (Sullivan and Smith 1993).

The main predators in cover crops and cotton during both years of the experiment were heliothine predators and aphidophagous lady beetles. The major heliothine predators were *G. punctipes, O. insidiosus,* and red imported fire ant, *Solenopsis invicta* Buren. Lady beetles included the convergent lady beetle, *Hippodamia convergens* Guérin-Méneville; the sevenspotted lady beetle, *Coccinella septempunctata* L.; spotted lady beetle, *Coleomegilla maculata* (DeGeer); and the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas). All of these predators have been reported to occur in fields with agronomic crops previously planted in crimson clover, hairy vetch, and rye cover crops (Bugg et al. 1991, Ruberson et al. 1997, McCutcheon 2000).

Red imported fire ants were highest in the legume mixture and lowest in the rye in comparisons among the four cover crop treatments in spring 2001 (Table 5). Crimson clover was the only cover crop in which fire ants were present every sampling period. The next spring, fire ants were not significantly different in crimson clover, the legume mixture and the legume–rye combination, but significantly lower in the legume mixture compared with the other three cover crops (Table 6). In the summer of both years of the study, red imported fire ants were significantly greater in conservation tillage cotton fields planted with cover crops than in conventional tillage cotton fields left fallow during the winter (Tables 5 and 6). Ruberson et al. (1997) also reported that red imported fire ants were more abundant in conservation tillage plots than in conventionally tilled plots. In our study in summer 2001, crimson clover and rye cotton harbored significantly higher numbers of the red imported fire ants than legume and legume–rye cotton. The next cotton season, however, numbers of this predator were sig-

Table 5. Least squares means for predators in sweep samples in all cover crops treatments in 2001

Crop type	Treatment	n^a	Fire ants	n	*G. punctipes*	n	*O. insidiosus*	n	Lady beetles
Cover crop	Legume mixture[b]	1067	0.61 ± 0.02a2	1067	0.77 ± 0.03b1	780	1.55 ± 0.06a1	1067	0.96 ± 0.03a1
	Crimson clover	1004	0.56 ± 0.01b2	1004	0.86 ± 0.02a1	1004	0.97 ± 0.03b1	1004	0.74 ± 0.02b2
	Legume[c] + rye	738	0.56 ± 0.02b2	738	0.53 ± 0.01c2	536	0.70 ± 0.03c1	738	0.67 ± 0.02c2
	Rye	724	0.51 ± 0.01c2	362	0.51 ± 0.01d2	724	0.55 ± 0.01d1	724	0.65 ± 0.02c2
Cotton	Legume mixture	439	1.00 ± 0.06b1	439	0.66 ± 0.03ab2	439	0.51 ± 0.01b2	439	0.88 ± 0.04c1
	Crimson clover	384	1.22 ± 0.07a1	384	0.75 ± 0.03a2	384	0.54 ± 0.02a2	384	0.91 ± 0.04bc1
	Legume + rye	315	1.04 ± 0.06b1	315	0.65 ± 0.03b1	315	0.52 ± 0.01ab2	315	0.90 ± 0.04bc1
	Rye	315	1.23 ± 0.07a1	315	0.67 ± 0.03ab1	315	0.54 ± 0.02ab1	315	1.01 ± 0.06b1
	Control	420	0.76 ± 0.03c	420	0.63 ± 0.03b	420	0.59 ± 0.02ab	420	1.19 ± 0.04a

Least squares means within a column followed by the same number are not significantly different between crop types for a single cover crop treatment, and least squares means within a column followed by the same letter are not significantly different between cover crop treatments for a single crop type (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for rye and legume mixture + rye treatments are *n*-30 for cover crop type. Degrees of freedom for crimson clover and the legume mixture are *n*-33 for cover crop type. Degrees of freedom for all treatments in the cotton crop type are *n*-15.

[b] Legume mixture is balansa clover, crimson clover, and hairy vetch.

[c] Legume mixture.

Table 6. Least squares means for predators in sweep samples in all cover crops treatments in 2002

Crop type	Treatment	n^a	Fire ants	n	*G. punctipes*	n	*O. insidiosus*	n	Lady beetles
Cover crop	Legume mixture[b]	891	0.53 ± 0.01b2	891	0.90 ± 0.02a1	891	0.94 ± 0.02b1	891	0.75 ± 0.02a1
	Crimson clover	729	0.58 ± 0.01a2	729	0.88 ± 0.02a1	729	1.03 ± 0.02a1	729	0.76 ± 0.02a1
	Legume[c] + rye	891	0.57 ± 0.01a2	891	0.54 ± 0.01b1	891	0.58 ± 0.01c1	891	0.61 ± 0.01b2
	Rye	729	0.57 ± 0.01a2	405	0.51 ± 0.01c2	567	0.55 ± 0.01d1	729	0.57 ± 0.01b2
Cotton	Legume mixture	336	0.86 ± 0.03ab1	336	0.58 ± 0.01a2	192	0.55 ± 0.01a2	336	0.71 ± 0.02b2
	Crimson clover	264	0.87 ± 0.03ab1	264	0.60 ± 0.01a2	120	0.51 ± 0.01b2	264	0.70 ± 0.03b2
	Legume + rye	336	0.91 ± 0.03a1	264	0.53 ± 0.01b1	264	0.53 ± 0.01b2	336	0.75 ± 0.02b1
	Rye	264	0.80 ± 0.03b1	192	0.59 ± 0.02a1	264	0.55 ± 0.01a1	264	0.88 ± 0.03a1
	Control	192	0.59 ± 0.02c	336	0.58 ± 0.01a	336	0.56 ± 0.01a	336	0.77 ± 0.02ab

Least squares means within a column followed by the same number are not significantly different between crop types for a single cover crop treatment, and least squares means within a column followed by the same letter are not significantly different between cover crop treatments for a single crop type (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

[a] Refers to the number of sweep samples for each cover crop treatment field for each sampling location for each sampling week. Degrees of freedom for all treatments are *n*-27 for cover crop type. Degrees of freedom for all treatments in the cotton crop type are *n*- 12.

[b] Legume mixture is balansa clover, crimson clover, and hairy vetch.

[c] Legume mixture.

nificantly lower in rye than in the other three treatments with cover crops.

Except for the blend cover treatment in 2001, red imported fire ants were significantly higher in cover crop fields for both years for the first sampling date in cotton compared with the last sampling date in the cover crops just before cotton was planted (Fig. 1). Red imported fire ants were significantly higher in all covers crop cotton fields than in control cotton field for 3 wk in 2001 and for 2 wk in 2002. Crimson clover cotton was the only cover crop treatment that consistently harbored greater numbers of this predator compared with the cotton controls up to the next to the last week before sampling ended.

For both years of the study, crimson clover and the legume mixture cover crops harbored significantly higher numbers of *G. punctipes* and *O. insidiosus* compared with the two cover crop treatments with rye, and numbers of these two predators were significantly greater in the legume–rye combination treatment than in rye (Tables 5 and 6). Only the crimson clover and legume cover crop treatments harbored significantly higher numbers of *G. punctipes* in the cover crops in the spring compared with cotton in the summer. All three legume treatments harbored significantly higher numbers of *O. insidiosus* in the cover crops compared with cotton. These results suggest that the legumes were better host plant habitats for both of these predators in the spring than the grass. In spring 2001, *G. punctipes* was significantly higher in crimson clover treatments than in any of the other cover crop treatments, indicating that this predator was highly attracted to this legume (Table 5). For pooled sampling dates in 2001, density of *G. punctipes* was significantly higher in cotton fields previously planted in crimson clover compared with control cotton fields. In contrast, there was no significant difference in the number of *O. insidiosus* between crimson clover cotton and control cotton for 2001, and the number of this predator in the crimson clover cotton fields was lower than that for the control fields the following summer.

For crimson clover and the legume mixture for both years, *G. punctipes* was not significantly different between the last week of sampling in the cover crop and the first week cotton was sampled (Fig. 2). However, for the rye treatments, density of *G. punctipes* was significantly higher the first week in cotton compared with the last week in the cover crop for both years of the study. This same phenomenon occurred for legume-rye treatments in 2002. This predator also was significantly higher in all cover crop treatments compared with control cotton for the second week of sampling in cotton in 2001 and in crimson clover and rye compared with control cotton for the first week of sampling in cotton in 2002. The number of *O. insidiosus* was not significantly different in any cover crop cotton treatment relative to control cotton for any sampling date (Fig. 3).

For both years of the study, crimson clover and the legume mixture harbored significantly higher levels of lady beetles compared with the two cover crop treatments with rye, indicating that the legumes were a more suitable habitat for lady beetles than the grass in the spring (Tables 5 and 6). For pooled sampling dates in 2001, the number of lady beetles was significantly higher in cotton for all cover crop treatments, except the legume mixture, than for the cover crops in the spring. Nevertheless, the number of lady beetles in control fields was still significantly higher than in the other four cover crop treatments in cotton. In 2002, the number of lady beetles was significantly higher in cotton than in cover crops for only the legume–rye and rye treatments. In cotton, lady beetles were significantly higher in rye cotton than in cotton intercropped in the three other cover crops, but no significant differences occurred in numbers of lady beetles between the fields with cover crops and control fields.

Except for the legume mixture, lady beetles were significantly higher for the first sampling week in cotton than for the last week of sampling in the cover crop in 2001 (Fig. 4). For that same year, crimson clover and legume mixture cotton were the only two cover crop treatments that had consistently lower numbers of lady beetles than the control fields over the first four sampling weeks. In 2002, the number of lady beetles was not significantly different between the last week of sampling in the cover crop and the first week cotton

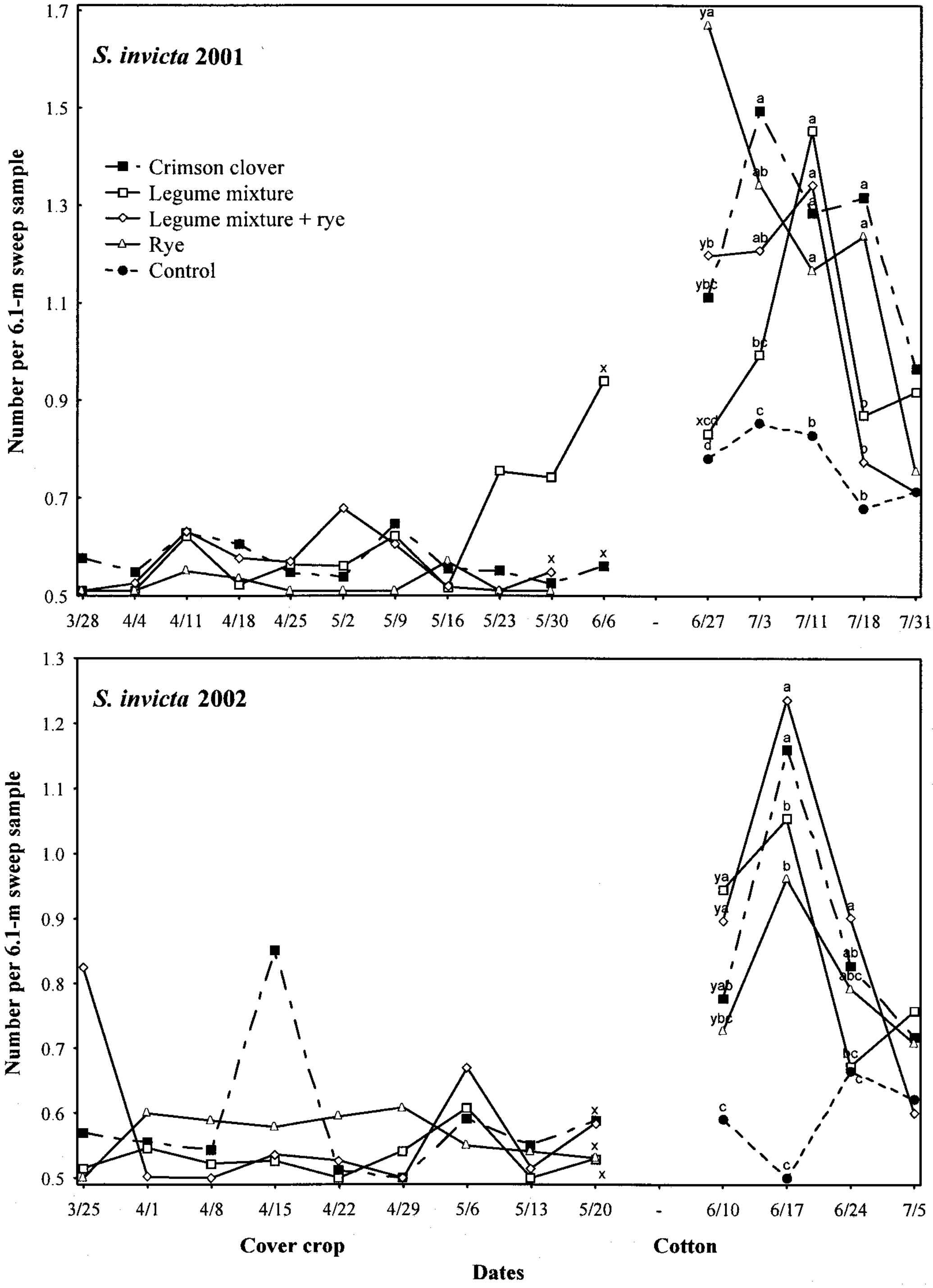

Fig. 1. Comparison of activity over time in 2001 and 2002 by *S. invicta* among cover crop treatments rye, crimson clover, legume mixture (balansa clover, crimson clover, and hairy vetch), legume mixture + rye, and no cover crop with subsequent conventional tillage in cover crops in the spring and in cotton in the early summer. Least squares means followed by the same letter (x,y) are not significantly different between the last sampling date in cover crop and the first sampling date in cotton for a single cover crop treatment, and least squares means followed by the same letter (a–d) are not significantly different between cover crop treatments for a single sampling date in cotton (one-tailed t-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

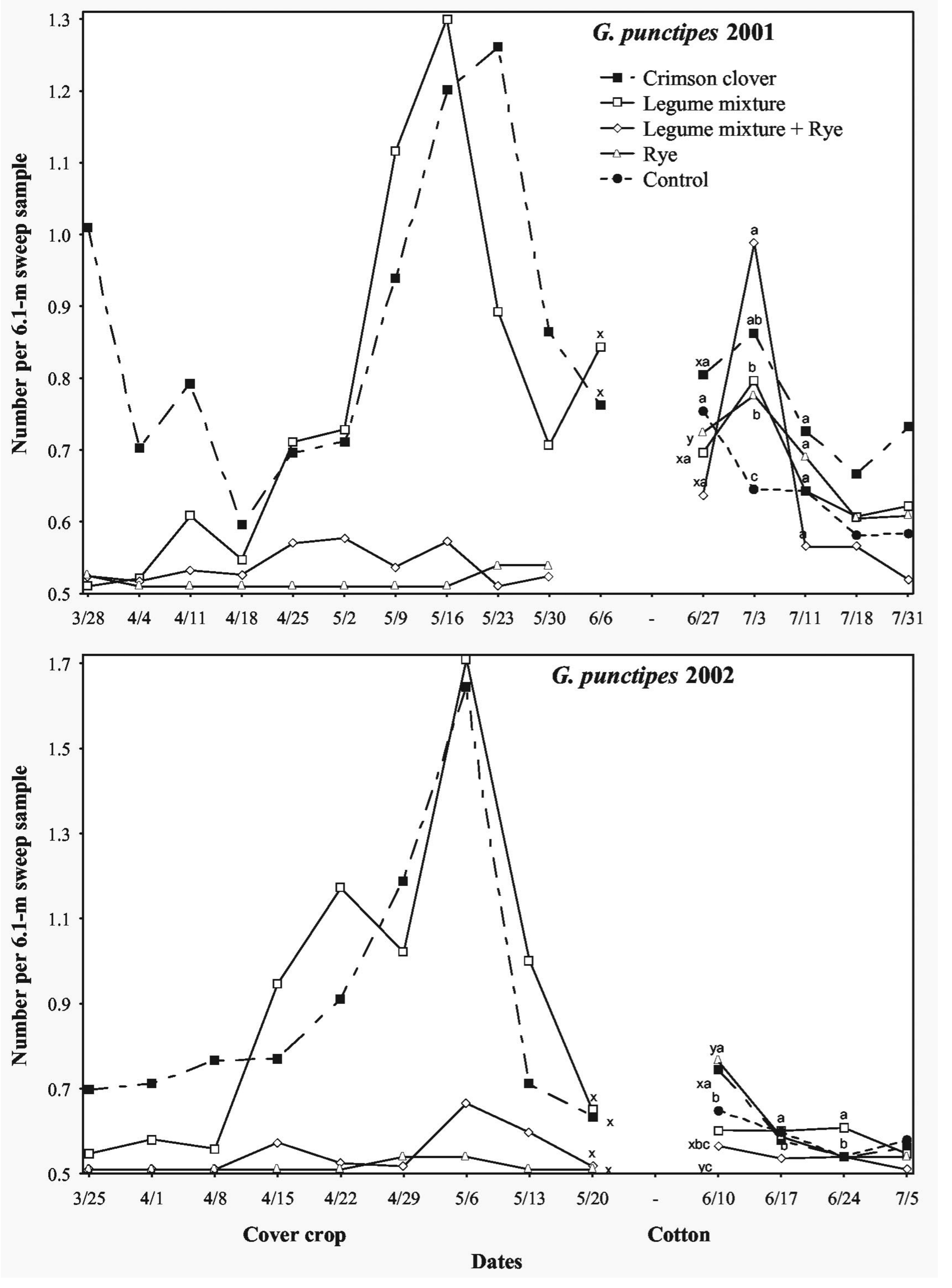

Fig. 2. Comparison of activity over time in 2001 and 2002 by *G. punctipes* among cover crop treatments rye, crimson clover, legume mixture (balansa clover, crimson clover, and hairy vetch), legume mixture + rye, and no cover crop with subsequent conventional tillage in cover crops in the spring and in cotton in the early summer. Least squares means followed by the same letter (x,y) are not significantly different between the last sampling date in cover crop and the first sampling date in cotton for a single cover crop treatment, and least squares means followed by the same letter (a–d) are not significantly different between cover crop treatments for a single sampling date in cotton (one-tailed t-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

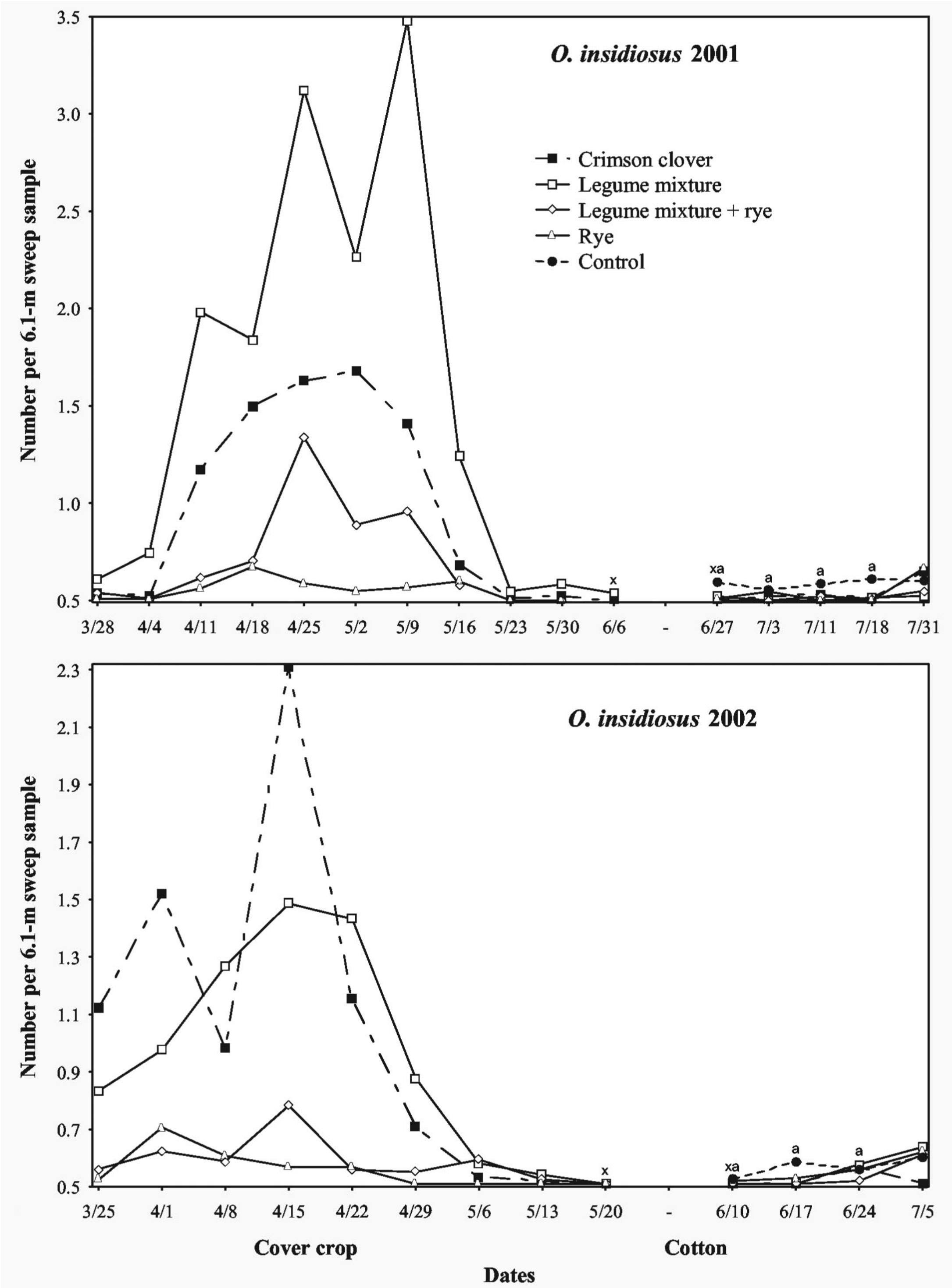

Fig. 3. Comparison of activity over time in 2001 and 2002 by *O. insidiosus* among cover crop treatments rye, crimson clover, legume mixture (balansa clover, crimson clover, and hairy vetch), legume mixture + rye, and no cover crop with subsequent conventional tillage in cover crops in the spring and in cotton in the early summer. Least squares means followed by the same letter (x,y) are not significantly different between the last sampling date in cover crop and the first sampling date in cotton for a single cover crop treatment, and least squares means followed by the same letter (a–d) are not significantly different between cover crop treatments for a single sampling date in cotton (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

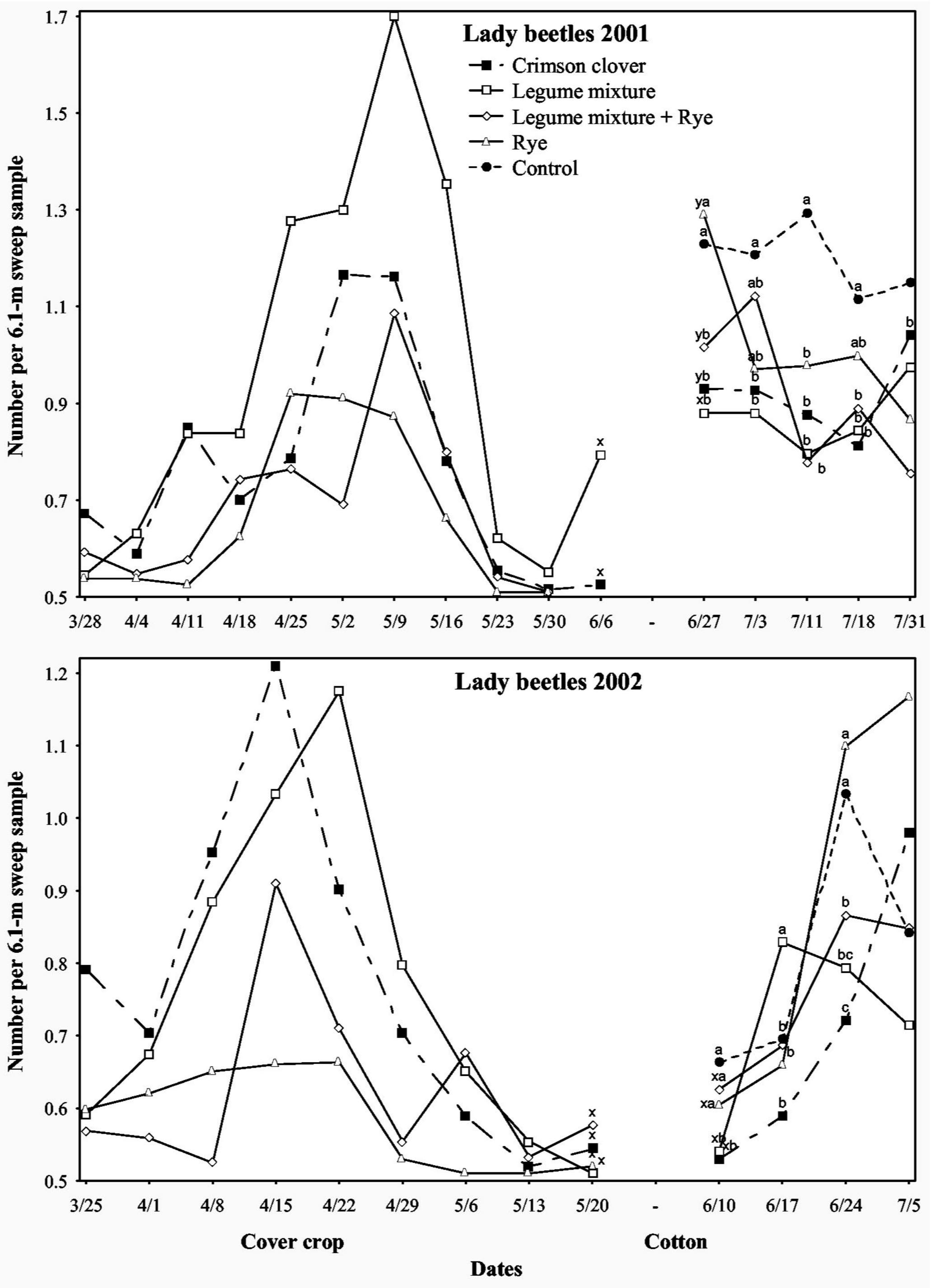

Fig. 4. Comparison of activity over time in 2001 and 2002 by lady beetles *H. convergens*, *C. septempunctata*, *C. maculata*, and *H. axyridis* among cover crop treatments rye, crimson clover, legume mixture (balansa clover, crimson clover, and hairy vetch), legume mixture + rye, and no cover crop with subsequent conventional tillage in cover crops in the spring and in cotton in the early summer. Least squares means followed by the same letter (x,y) are not significantly different between the last sampling date in cover crop and the first sampling date in cotton for a single cover crop treatment, and least squares means followed by the same letter (a–d) are not significantly different between cover crop treatments for a single sampling date in cotton (one-tailed *t*-statistics of least squares means applied to square-root transformed data, $P > 0.05$).

Table 7. Least squares means for seed cotton yield for all cover crop treatments in 2001 and 2002

Treatment	Seed cotton yield (kg/ha) 2001		Seed cotton yield (kg/ha) 2002	
	n^a	Mean ± SE	n	Mean ± SE
Crimson clover	3	3778.2 ± 249.6a	3	2026.2 ± 235.8a
Legume mixture[b] + rye	3	3586.0 ± 249.6ab	3	2161.3 ± 164.1a
Rye	3	3304.2 ± 249.6abc	3	1390.4 ± 222.8b
Legume mixture	4	3045.4 ± 222.8bc	4	2031.0 ± 244.4a
Control	4	2822.2 ± 222.8c	4	1072.4 ± 57.3b

Least square means within a column followed by the same letter are not significantly different between treatments (PROC MIXED, LSD, $P > 0.05$).

[a] Refers to the number of fields for each cover crop treatment.

[b] Legume mixture is balansa clover, crimson clover, and hairy vetch.

was sampled for all cover crop treatments (Fig. 4). The number of lady beetles was significantly lower in cotton for all legume cover crops compared with control cotton the third week of sampling in cotton.

Seed cotton yields were significantly different among treatments for 2001 ($F = 4.07$; df = 4, 25; $P = 0.01$) and 2002 ($F = 6.2$; df = 4, 17; $P = 0.01$) (Table 7). In the first year of the test, seed cotton yields were significantly higher for cotton with crimson clover and legume mixture–rye combination than for control cotton without cover crops, whereas the yields for the legume mixture and rye treatments were not significantly different from those for the controls. In 2002, all cover crop cotton fields, except for the rye fields, had significantly higher seed cotton yields compared with control fields. Because yields for cover crop treatments were never lower than those for control cotton, we concluded that planting cotton in strip-killed and strip-tilled cover crops did not adversely affect cotton production. Similarly, Scott et al. (1990) reported that cotton grown after rye, hairy vetch, rye + vetch, and rye + crimson clover had higher yields than control fields with no winter cover crop over a 10-yr period. In contrast, both Gaylor et al. (1984) and Ruberson et al. (1997) reported that cotton yields were reduced in crimson clover cotton fields, but similar in rye fields, compared with control fields without a cover crop. Availability of new strip-tilling technology may account for the better cotton yields that we obtained for crimson clover fields compared with control fields.

Discussion

In this on-farm study, we compared conventional tillage and winter fallow practices with strip-tillage with four diverse cover crops designed to enhance natural enemies in cotton by promoting the increase of populations of these natural enemies in the spring and encouraging these natural enemies to relay from the spring cover crops into cotton. The goal of mixing the three legume species was to extend flowering to promote better relay of predators from the cover crop to cotton. Timing of initial flowering and seasonal succession of flowering for these cover crops occurred so that the numbers of *G. punctipes*, *O. insidiosus*, and lady beetles built up in the spring in the cover crops, especially in the legume mixture and crimson clover treatments. By strip-killing and strip-tilling the legume cover crops, a live strip of cover crop was available as a habitat for the natural enemies in the late spring when cotton was planted. Because density of *G. punctipes* present on the first sampling date in cotton was similar to density on the last sampling date in legume mixture and crimson clover cover crops in 2001 and 2002, we conclude that *G. punctipes* relayed from these cover crops onto cotton. Also, *G. punctipes* was higher in crimson clover and legume mixture fields compared with control fields for combined or single sampling dates, indicating that the buildup of this natural enemy in the spring translated into higher density of these predators in crimson clover and legume mixture cotton than in control cotton. *G. punctipes* may have dispersed from crimson clover and the legume mixture quicker in 2002 than 2001 because plant senescence occurred earlier in 2002 than in 2001.

Enhancement of *G. punctipes* in conservation tillage cotton has not been previously reported for this predator for any cover crop. Gaylor et al. (1984) reported that at the time of peak heliothine population density on cotton, significantly more predators, *Geocoris* spp. and spiders, existed on cotton in the conventional tillage treatments than in the conservation tillage treatments with cover crops. The stressed condition of the cotton grown under conservation tillage with crimson clover as a cover crop may have been responsible for the lower populations of these predators observed in crimson clover cotton compared with control cotton. Ruberson et al. (1995) reported that in summer 1994, populations of *G. punctipes* were reduced in a conservation tillage cotton field relative to a conventional tillage cotton field. In a second study conducted by Ruberson et al. (1997) no differences in *G. punctipes* populations were detected between crimson clover cotton and conventional tillage cotton without a cover crop. In our study, we maintained a strip of live crimson as a habitat for *G. punctipes*, whereas in the other reported studies the crimson clover was completely killed before planting the main crop. Maintaining this live strip of cover crop was probably responsible for the relay of *G. punctipes* in crimson clover cotton fields. Similarly, research on strip crops in cotton indicated that a live strip crop was necessary to effectively relay predators between a strip crop and cotton, Parajulee and Slosser (1999). In the spring, vetch harbored high numbers of predators, but predator enhancement was not significant in cotton plots adjacent to vetch for one season presumably because there was a lack of temporal overlap between the strip crop and cotton. In contrast, grain sorghum harbored numerically lower numbers of predators than vetch, but this strip crop served as an effective relay of predators to adjacent cotton for both seasons of the test since there was a temporal overlap between the two crops.

Lady beetles probably did relay from cover crops into cotton because numbers of lady beetles for the first sampling date in cotton was not significantly different from or higher than that for the last sampling date in the cover crops. Even so, lady beetles were relatively more abundant in control cotton than in cotton for all cover crops in 2001 and for legume-rye, legume mixture and crimson clover treatments in 2002. Thus, lady beetles probably also dispersed from other plant species in the agricultural landscape into the cotton agroecosystem.

Conservation of habitat of fire ants during planting probably was responsible for the higher density of red imported fire ants in conservation tillage cotton with cover crops relative to control cotton. Similarly, Ruberson et al. (1995) reported that the presence of red imported fire ants in clover fields may have been a function of reduced tillage than use of the cover crop. McCutcheon et al. (1995) demonstrated that densities of the red imported fire ant were highest in cotton in noncultivated plots that had a crimson clover cover compared with cultivated plots. In a later study, McCutcheon (2000) determined that fire ants were more abundant in rye–no-tillage treatments than in rye–disk treatments.

Because red imported fire ants actively defend aphids from predators such as lady beetles (Vinson and Scarborough 1989), populations of cotton aphid were higher with increased activity of these fire ants in cover crop cotton fields compared with control cotton fields. Other studies have shown that aphids were more abundant in conservation tillage plots with high density fire ant populations than in conventional tillage plots (Ruberson et al. 1997, McCutcheon 2000). In contrast, Leser (1995) reported that the cotton aphid was reduced in cover crops and conservation tillage systems. The relationships of cotton aphids to the red imported fire ant and natural enemies of the cotton aphid, lady beetles, *Chrysoperla* spp., and the fungus, *Neozygites fresenii* (Nowakowski) are so intertwined that it can be difficult to accurately predict the impact that any of the specific cover crops, except rye, has on this pest and its natural enemies. For example, relative abundance of cotton aphids was high in cotton fields previously planted in rye, and numbers red imported fire ants and lady beetles were relatively high in these fields for both years of the study. Also, lower densities of red imported fire ants were found in legume mixture and legume–rye cotton compared with the rye and crimson clover treatments when densities of cotton aphids were also lower in the two former treatments compared with the latter two treatments in 2002. However, in these legume mixture and legume–rye cotton fields in 2001 and in crimson clover cotton fields in 2002, even though aphid numbers were low in comparison with the other cover crop treatments, red imported fire ants were still relatively high in these fields compared with control cotton fields. Ruberson et al. (1995, 1997) observed that the more rapid buildup of aphids in conservation tillage plots than in conventional ones was typically followed by a more precipitous decline on conservation-tilled cotton.

H. virescens and *H. zea* females did not exhibit an ovipositional preference for any cover crop treatment during the cotton-growing season because they laid eggs equally on cotton for all five cover crop treatments, except for rye in 2002. Thus, differential oviposition was not responsible for differences detected between cover crop treatments for first instars of heliothine densities and the number of times economic thresholds were exceeded (except possibly for rye in 2002). Reduction in the number of dates in which economic thresholds for heliothines were exceeded in crimson clover and rye compared with control fields indicates that the buildup of predaceous fire ants and *G. punctipes* in crimson clover and rye subsequently resulted in reduction in the level of heliothines in these cover crop compared with control cotton fields. *G. punctipes* is known to be one of the most predominant and effective predators of *H. zea* and *H. virescens* in cotton (Bell and Whitcomb 1963, Lopez et al. 1976), and fire ants have been reported to be excellent predators of a variety of cotton pests (Showler and Reagan 1987). The report of McCutcheon et al. (1995) indicated that the higher densities of fire ants in noncultivated compared with cultivated plots possibly resulted in the reduced densities of heliothine eggs in noncultivated plots versus cultivated ones is in agreement with our conclusions about the suppressive activity of fire ants against heliothines in conservation tillage cotton.

Relay of natural enemies in cash crops has been shown to enhance densities of natural enemies in these crops when they are intercropped with winter cover crops. The concept is to plant the crop by using reduced tillage to maintain the natural enemies in strips of the cover crop so that as the cover crop dies, these natural enemies will relay or disperse into the main crop. Bugg et al. (1991) used seven different winter cover crops and a weedy fallow treatment in a relay intercropping scheme with spring-sown cantaloupe, *Cucumis melo* L. *G. punctipes* occurred in higher densities on subterranean clover, *Trifolium subterraneum* L., than on other cover crops, including crimson clover and hybrid vetch, and there was evidence that high densities observed amid dying mulches translated into greater predation of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) egg masses on cantaloupe foliage. Altieri et al. (1985) reported that herbivores were more abundant in weed cover than in living red clover mulch and higher numbers of natural enemies were observed in the clover plots in corn; tomato, *Lycopersicon esculentum* Mill.; and cauliflower, *Brassica oleracea* L. variety *botrytis* crop systems in one research site in California. Other examples of experiments documenting that diversification of cropping systems often leads to reduced pest populations are in cited in Altieri (2002). The problem is not in understanding or acknowledging the ecological soundness of the concept but in implementing it in ways that are grower friendly.

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